UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DTNSRDC-80/058	2. GOVT ACCESSION NO. AD-A084 226	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DEVELOPMENT OF HIGH LIFT DEVICES FOR APPLICATION TO ADVANCED NAVY AIRCRAFT		5. TYPE OF REPORT & PERIOD COVERED Final repts
		6. PERFORMING ORG. REPORT NUMBER Aero Report 1266
7. AUTHOR(s) James H. Nichols, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship Research and Development Center Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (See reverse side)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Material Command (08T23) Naval Air Systems Command (320D) Washington, D.C. 20361		12. REPORT DATE April 1980
		13. NUMBER OF PAGES 47
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

WF41421091, ZF41421001

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DTNSRDC/AERO-1266

F41421

18. SUPPLEMENTARY NOTES

Presented at Workshop on V/STOL Aerodynamics
Naval Post Graduate School, Monterey, California
16-18 May 1979

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aerodynamics	Upper Surface Blowing
High Lift	Wing Tip Sails
Circulation Control Wing	Flight Test
Winglets	Wind Tunnel Test
Propulsive Lift	STOL

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A number of methods for generating high lift to provide a short takeoff and landing (STOL) capability for advanced Navy aircraft are evaluated, with emphasis on low aspect ratio wings. Upper surface blowing, circulation control wing, and wing tip sails are given the most attention. Experimental data are being obtained in the DTNSRDC wind tunnels on these concepts as specifically applied to wings of aspect ratios 3 to 5. Flight demonstrations

(Continued on reverse side)

(Block 10)

Program Element 62241N, WF 41.421.091
Task Areas (1600-079-30) and ZF41.421.001
Work Unit 1660-606

(Block 20 continued)

by Grumman and DTNSRDC of a circulation control wing application to the A-6 aircraft have shown the ability to more than double the lifting capability which resulted in landing speed reductions of more than 30 percent, landing ground roll reductions of more than 50 percent, and takeoff distance reductions of at least 25 percent. The experimental high lift system data have been applied to a conceptual STOL baseline aircraft in order to estimate the impact on mission performance and identify their various merits as applicable to the particular restrictions of small ship operations.

Accession For
NTIS GRA&I ☐
DDC TAB ☐
Unannounced ☐
Justification

By
Distribution/
Availability Codes

Dist.	Avail and/or special
A	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A number of methods for generating high lift to provide a short takeoff and landing (STOL) capability for advanced Navy aircraft are evaluated, with emphasis on low aspect ratio wings. Upper surface blowing, circulation control wing, and wing tip sails are given the most attention. Experimental data are being obtained in the DTNSRDC wind tunnels on these concepts as specifically applied to wings of aspect ratios 3 to 5. Flight demonstrations by Grumman and DTNSRDC of a circulation control wing application to the A-6 aircraft have shown the ability to more than double the lifting capability which resulted in landing speed reductions of more than 30 percent, landing ground roll reductions of more than 50 percent, and takeoff distance reductions of at least 25 percent. The experimental high lift system data have been applied to a conceptual STOL baseline aircraft in order to estimate the impact on mission performance and identify their various merits as applicable to the particular restrictions of small ship operations.

ADMINISTRATIVE INFORMATION

The high lift aerodynamics work described herein is being performed as part of the DTNSRDC Aerodynamics Block (WF 41.421.091) sponsored by the Naval Air Systems Command (AIR 320D). The A-6/Circulation Control Wing Flight Demonstration Program was completed for the Naval Material Command (MAT 08T23) as a Direct Laboratory Funded (DLF) Program (ZF41.421.001) with support from the Naval Air Systems Command. Contractor support in this latter program was provided by Grumman Aerospace Corporation (Contracts N00019-76-C-0243 and N00600-77-C-0674).

CONVERSION TABLE

The following conversions from English to Metric Units are included for the reader's convenience.

foot × 0.305 = meter

pound mass × 0.454 = kilogram

pound force × 4.448 = newton

T/W (pound force per pound mass) × 9.807 = T/W (newtons per kilogram)

W/S (pound mass per square foot) × 4.882 = W/S (kilograms per square meter) nautical miles × 1.852 = kilometers

knots × 1.852 = kilometers per hour

pounds per square inch gage × 6.895 = kilopascals (gage)

pounds per square foot × 0.048 = kilopascals

degrees × 0.017 = radians

INTRODUCTION

Operating fixed wing aircraft from ships imposes a number of unique size constraints and performance requirements on the aircraft. This is particularly true for aircraft wing span and takeoff and landing performance. For vertical and short takeoff and landing (V/STOL) or STOL aircraft to be effective, they must be able to operate from small deck areas that preclude conventional aircraft operations. A strong implication of these requirements to aircraft design is the need for improved propulsion and high lift systems. However, the size constraints and speed requirements tend to force reductions in both wing span and aspect ratio.

A number of methods are under development for generating high lift, however, this work has been directed at applications to higher aspect ratio wings. The objective of the effort at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) is to provide the maximum effectiveness of powered high lift systems for low aspect ratio wings. A significant part of the effort is directed at better understanding the phenomena occurring between the regions of high energy strong circulation air and low energy or free-stream air. In particular, it is felt that mechanical devices with or without supplementary blowing must be incorporated with a powered high lift system to make it useful, at least for wings of lower aspect ratios. Furthermore, these same high lift enhancement devices may also increase the effective aspect ratio and thereby improve cruise performance if appropriately designed.

The high lift systems being developed appear to fall into three categories based on the amount of energy required to operate the system:

Category A - High lift produced by high propulsive energy input

Category B - High lift produced by low propulsive energy input

Category C - High lift produced by no propulsive energy input (mechanical systems)

Category A systems can be currently characterized by significant thrust-lift coupling while Categories B and C systems are relatively thrust-lift independent. Category A systems examined were externally blown flap (EBF), upper surface blowing (USB), combined surface blowing (CSB), and augmenter jet flap (AJF). The Category B system considered was the circulation control wing (CCW). The double slotted flap (DSF) was selected from Category C devices to serve as a state-of-the-art baseline for conventional unpowered high lift systems in order to compare lift and performance benefits of the powered systems.

A conceptual STOL baseline aircraft was developed to allow an assessment of the ability to perform a typical S-3 ASW type of mission with each of the high lift devices. A STOL aircraft was chosen since the impact of the high lift devices would have more visibility. It was this assessment that highlighted mission performance deficiencies for the required limited wing spans, thereby substantiating a need for additional help for the high lift device operation. Furthermore, in addition to presenting a challenge for useful high lift devices, low aspect ratio wings typically suffer in cruise performance. However, if the devices that can help high lift performance are designed properly, they may also improve cruise performance. Anticipated methods of such high lift and cruise enhancement are winglets (unblown or blown), wing tip sails (fixed or adjustable), fences, wing tip blowing, and leading edge devices. Each of these approaches has been shown to provide improvements in either lift or cruise.

The specific effort at this time involves aspect ratios from 3 to 5 and has been narrowed down to the double slotted flap (Category C), the circulation control wing (Category B), and upper surface blowing (representing Category A) for evaluating high lift and cruise enhancement devices.

ASSESSMENT OF CURRENT HIGH LIFT TECHNOLOGY

Several approaches to generating high lift are currently under development (Figure 1). Of the several systems looked at in the initial stages of this work, data were most readily available for the following systems:

1. Augmented jet flap (AJF)
2. Externally blown flap (EBF)

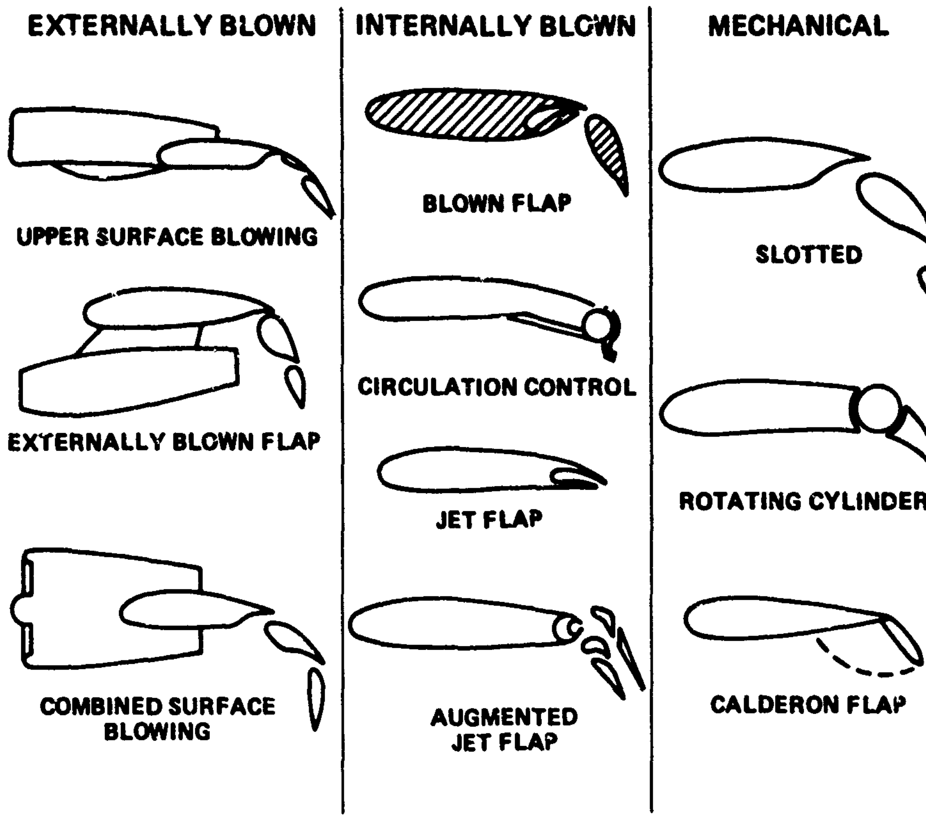
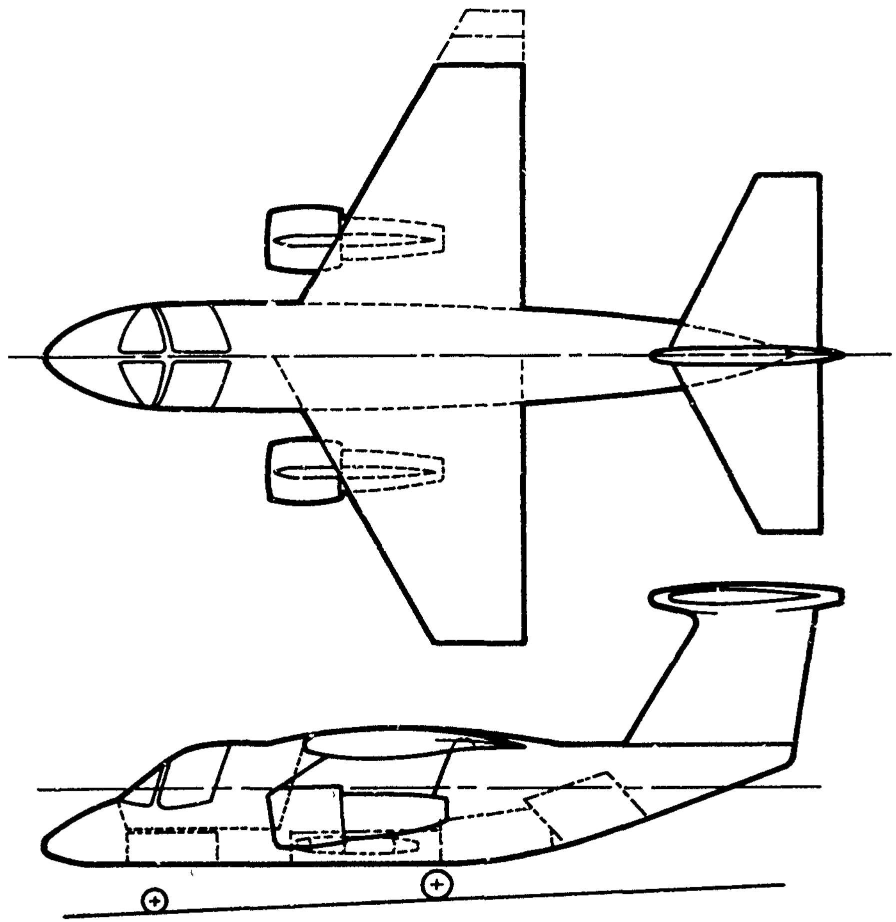


Figure 1 - High Lift Aerodynamics

3. Combined surface blowing (CSB)
4. Upper surface blowing (USB)
5. Circulation control wing (CCW)

The focus of the preliminary evaluation was on these systems, however, it became readily apparent that all data available were for wings of relatively high aspect ratio. Therefore, an experimental program would certainly be required for any further effort for low aspect ratio wings. For this reason, part of the initial assessment was conducted with the intent of narrowing down the number of concepts to keep such an experimental program within manageable bounds.

In order to compare each of these high lift systems, a conceptual STOL aircraft was developed using a 14 percent thick supercritical wing (Figure 2). An analysis was performed comparing the effects of the



FUSELAGE:
LENGTH = 47.1 ft
MAX WIDTH = 6.80 ft
MAX HEIGHT = 8.55 ft

WING:
AR = 3.5, 4.25, 5.0
$C_t/C_r = 0.35$
$\Lambda_c/4$ = 22 deg
AIRFOIL—14 percent SUPERCRITICAL

PROPULSION:
2-SCALED BPR = 6.2 TURBOFANS

Figure 2 - Conceptual Baseline STOL Aircraft

different high lift systems on the wing span requirements of aircraft with low aspect ratio ($3.5 \leq AR \leq 5.0$) wings for an ASW type mission and a required take-off distance of 400 feet. Rather than sizing the aircraft to meet a certain mission radius, internal fuel was fixed and the aircraft was allowed to perform its maximum radius for the selected performance characteristics. Results were developed in terms of ranges of thrust-to-weight ratio (T/W) required to achieve the above constraints for a range of fixed internal fuel that would keep the aircraft gross weight below 55,000 pounds. Results of this analysis are summarized below, however, a major conclusion was reached:

> The ineffective high-lift capability of low-aspect ratio wings is difficult to overcome by powered high-lift systems alone.

Therefore, an additional emphasis was placed on the experimental program to not only improve the efficiency of the high lift system but also increase the effective aspect ratio with the same high lift enhancement devices.

AUGMENTED JET FLAP

The AJF operates on the ejector principle by taking a primary jet of engine fan bypass air and exhausting it downward through an adjustable flap system which further entrains secondary flow from the wing upper surface (Figure 1). This concept has the advantage of a reasonably effective engine-out capability. Experimental data were obtained for wings of aspect ratio 8.0 which achieved maximum lift coefficients $\left(C_{L_{max}}\right)$ on the order of 7 1/2 (Figure 3). This system has been installed and flown successfully on a modified C-8 Buffalo research aircraft in a Boeing and NASA effort.

A performance analysis indicated that the AJF configured baseline aircraft would have a mission radius capability slightly better than but similar to that of the USB configured baseline aircraft. In addition, the AJF system mechanism is fairly complex, this complexity extending over much of the wing span, thereby rendering it difficult and expensive to produce in model scale. Although the performance warrants further work and the high lift and cruise enhancement devices could very well be unique for this

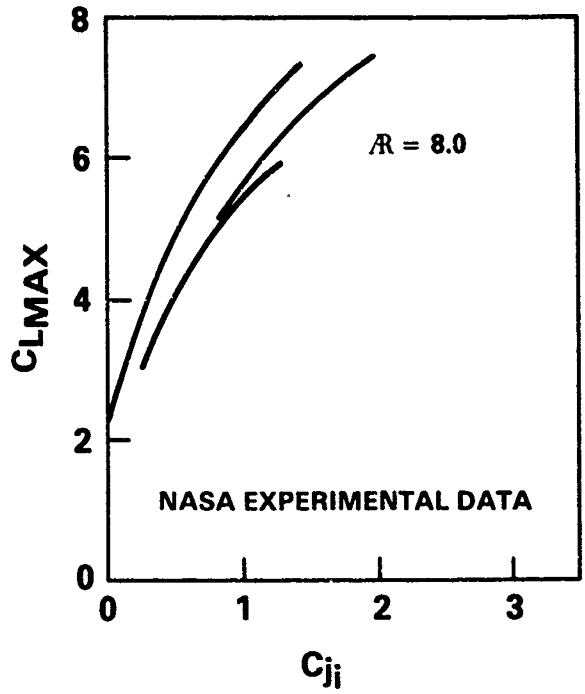


Figure 3 - Maximum Lift of Augmented Jet Flap

system, the decision was made to eliminate this system from the experimental program in deference to a system more readily modeled.

EXTERNALLY BLOWN FLAP

The EBF involves locating the engine ahead of and beneath the wing so that the engine exhaust creates a high velocity flow of air from near the leading edge and under the wing which then blows over a multielement flap (Figure 1). Very high values of $C_{L_{max}}$ on the order of 10 have been achieved experimentally (Figure 4). This system has been installed and successfully flown on the four-engine McDonnell-Douglas YC-15 aircraft. However, the system does not lend itself to having an engine-out capability for a two-engine installation and for this reason has been eliminated from further consideration in this program.

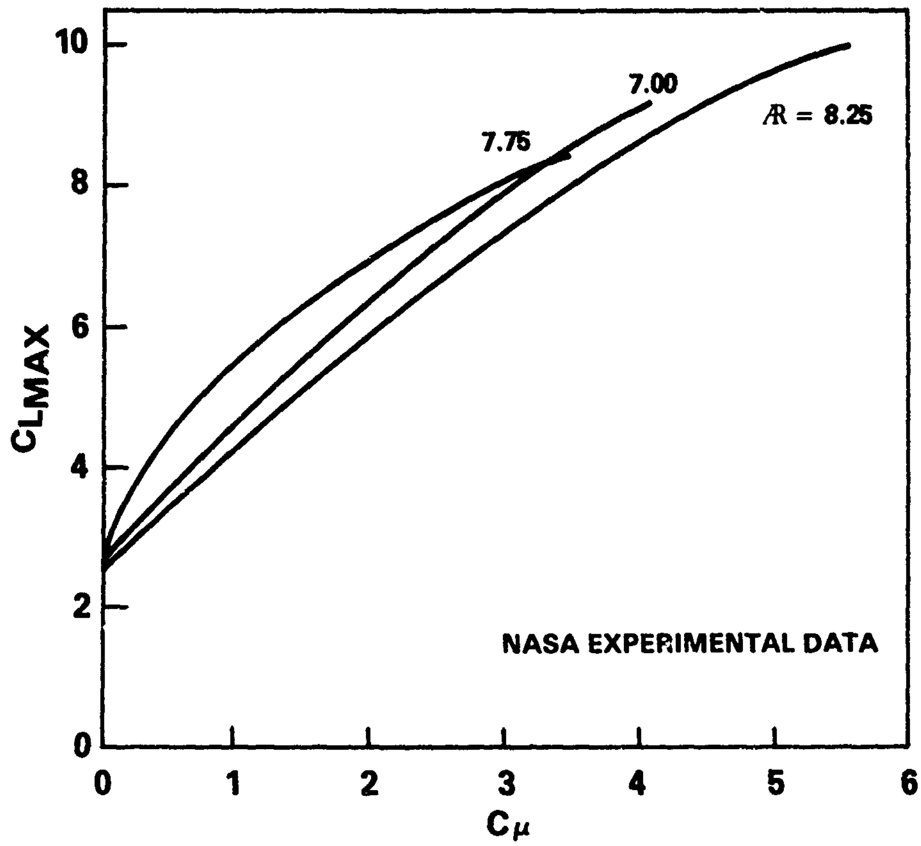


Figure 4 - Maximum Lift of Externally Blown Flap

COMBINED SURFACE BLOWING

The CSB places the flap within the engine fan exhaust adding high energy air to both the upper and lower surface of the wing and flap (Figure 1). The fans can be cross-shafted which provides a potential engine-out capability. NASA and Boeing Vertol experimental data have shown very high $C_{L_{max}}$ achievable (on the order of 12) and for aspect ratios getting close to the low range (Figure 5). Furthermore, the flow can be turned beyond 90 degrees (to around 105 degrees) which implies that a VTOL capability is conceivable with a high enough thrust to weight ratio. At least a good STOL capability should be achievable with this kind of thrust deflection.

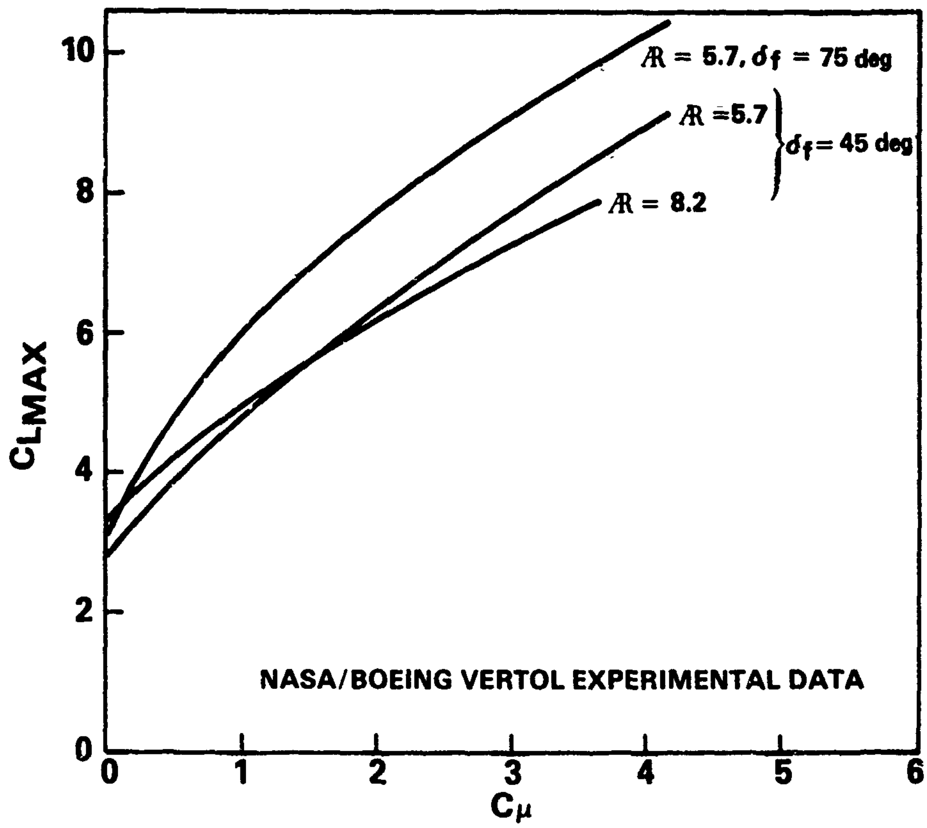


Figure 5 -- Maximum Lift of Combined Surface Blowing

This system shows high potential for contributing to the objectives of this work; it is planned to include this concept in the experimental program at some future time.

UPPER SURFACE BLOWING

The USB system involves Coanda turning of the engine exhaust over the upper surface of a smoothly curved flap. The resulting powered lift is due both to a component of the thrust vector and to increased circulation around the wing as a result of flow being entrained by the jet over the upper surface of the wing. This system has been installed and flown successfully on the Boeing YC-14 aircraft which incorporates a double-slotted flap system on the outboard portion of the wing. An effective engine out procedure has been established for this two-engine aircraft.

A substantial amount of wind-tunnel data has been generated for USB on high aspect ratio wings, a sampling of which is shown in Figure 6. These

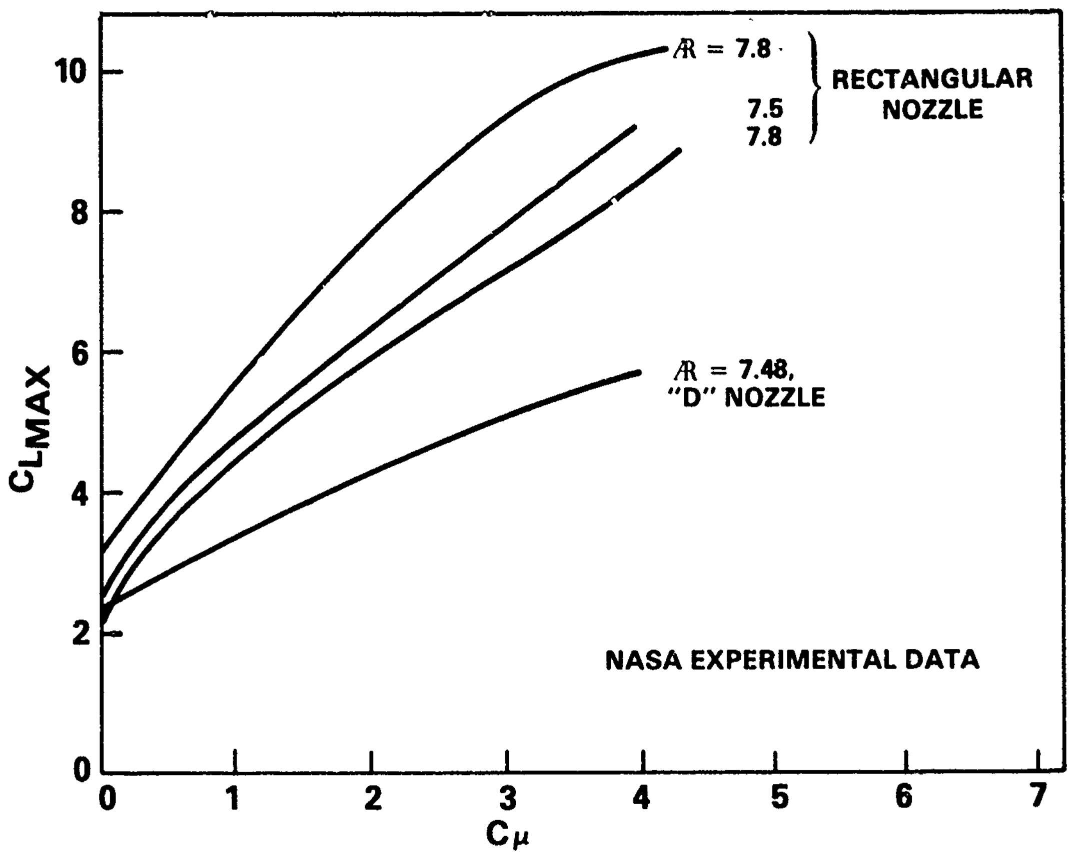


Figure 6 - Maximum Lift of Upper Surface Blowing

data show the importance of exit nozzle shape to generating high lift, although the effect of nozzle shape on cruise performance is not shown. The curved surface "D" nozzle is easily out-performed in lift generation by the "rectangular" nozzle. However, the "D" nozzle offers superior cruise performance and may, in fact, offer the best overall design. Also not shown in Figure 6 is the effect of nozzle aspect ratio for the rectangular nozzle, although values near 3 seem to offer the best lift performance.

The high aspect ratio experimental data were extrapolated to the low aspect ratios in order to conduct the performance analysis on the baseline aircraft. The wing loadings (W/S) required for a 400 foot deck run takeoff were determined for a range of thrust-to-weight ratios (T/W). This range of parameters, used with selected internal fuel weights, was used to generate aircraft configurations having aspect ratios of 5.0, 4.25, and 3.5. Mission radii were then determined for these designs and are shown versus takeoff weight (for the aspect ratio and T/W carpet) as shown in Figure 7. The wing span required is then superimposed on the figure.

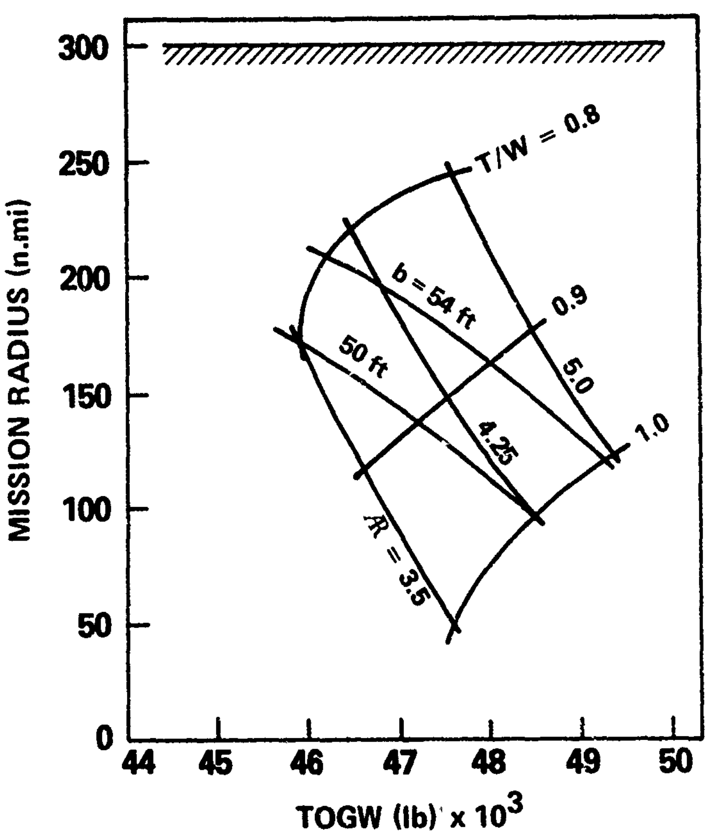


Figure 7 - Mission Performance Parameters for Low Aspect Ratio Wing STOL Aircraft with Upper Surface Blowing

Of considerable significance is the fact that the STOL USB aircraft configuration could achieve a 300 nautical mile radius mission within the desired range of parameters of T/W, aspect ratio, and takeoff gross weight. However, the configuration studied could not achieve a wing span within the 45 foot requirement for an amphibious assault (LPH) type ship. The USB system potentially offers considerable high lift performance--particularly with an appropriate engine and airframe match for both takeoff and cruise. Furthermore, integrating USB into a wind-tunnel model is relatively straightforward. Therefore, USB was selected for the low aspect ratio experiments for high lift and cruise performance enhancement, thus representing the Category A high propulsive energy class of high lift devices.

CIRCULATION CONTROL WING

The CCW concept involves controlling the stagnation points on the airfoil by means of a thin jet of air which remains attached to a rounded trailing edge (Coanda principle). By moving the stagnation points toward the center of the airfoil undersurface, the circulation around the airfoil is considerably increased, producing an effective camber much greater than the airfoil geometry dictates. An extensive amount of experimental data has been generated by DTNSRDC for both fixed wing and rotary wing applications. Several papers on the subject of fixed wing applications have been written by Englar and others (DTNSRDC).

The fixed wing effort was recently culminated in the highly successful flight demonstration of a CCW installation on an A-6 aircraft by Grumman and DTNSRDC[1*] (Figure 8). Details of the installation for the flight demonstration are shown in Figure 9. The objective of the flight program was a full-scale technology demonstration and as such the installation was designed as an add-on system using the A-6 aircraft. The A-6 was chosen for this role because of highly desirable airframe and propulsion system characteristics. The modifications to the aircraft were conservative to provide adequate safety and keep program costs to a minimum.

Lift performance demonstrated in the flight program is summarized in Figure 10. The best lift coefficient achieved was $C_L = 3.34$ at an angle

*A complete reference is given on page 39.

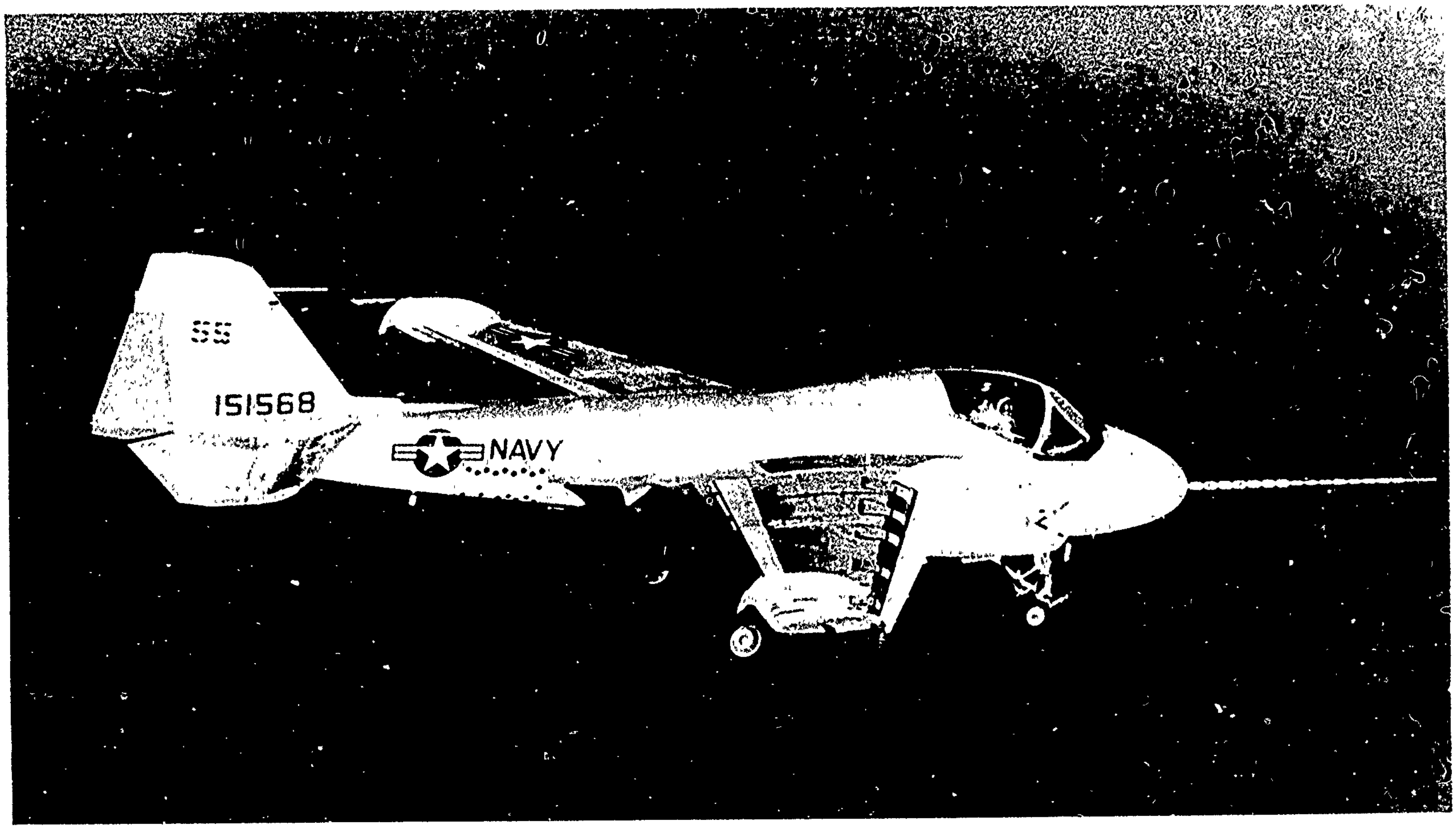


Figure 8 - Flight Demonstration A-6/CCW Aircraft

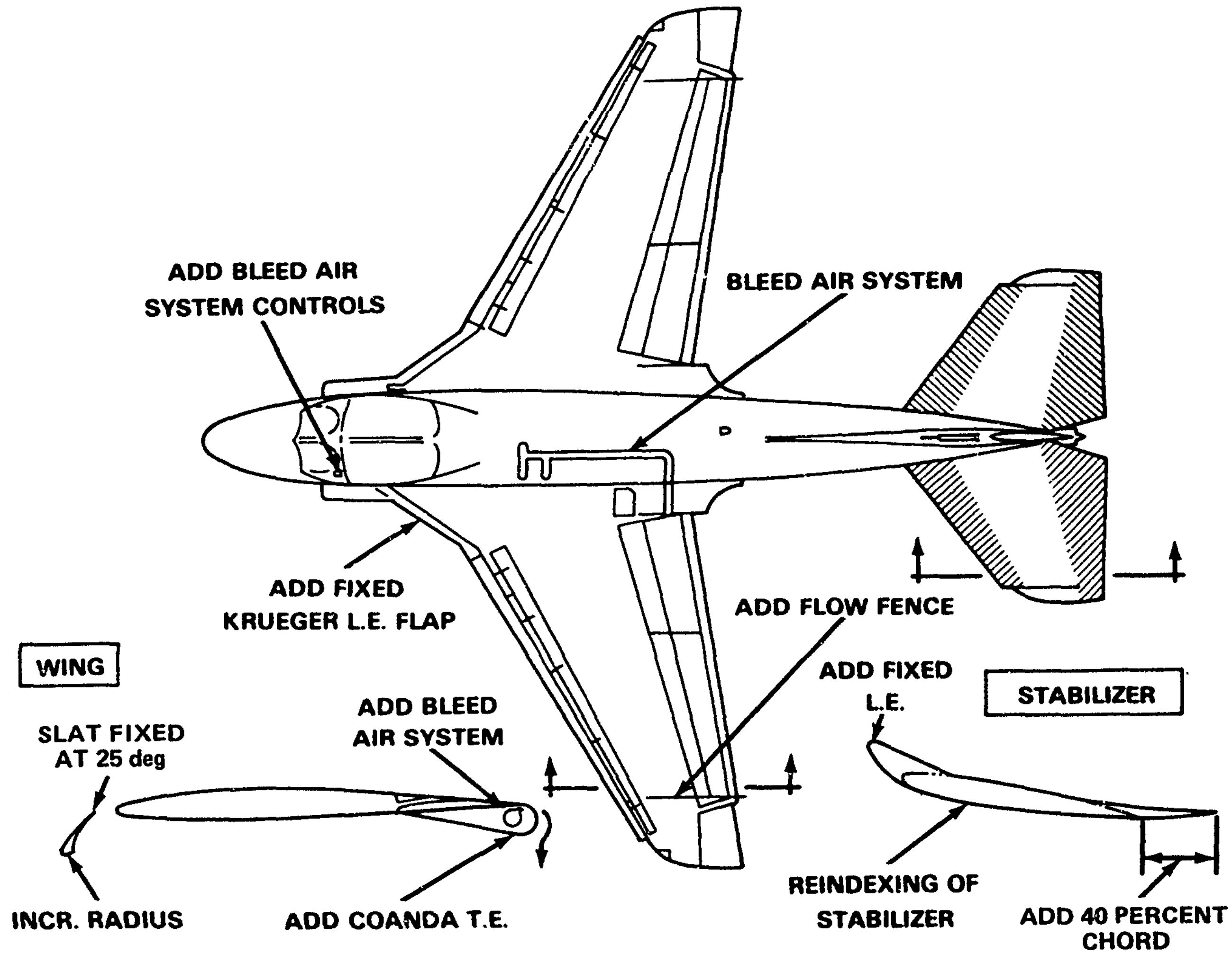


Figure 9 - Airframe Changes to A-6/CCW Aircraft

Altitude	Power* Setting	Pressure Ratio	Angle of Attack (deg)	C_μ	$C_{L_{Aero}}$	Indicated V (knots)
15,000	PLF	1.0	29.4	0	1.92	99
15,000	MT	4.4	8.9	0.093	2.23	101
12,000	MT	4.6	16.0	0.145	2.92	85
10,000	PLF	4.5	16.9	0.15	2.91	76
5,000	MT	3.7	16.0	0.20	3.34 (3.60**)	67

*MT = Military Thrust
PLF = Power for Level Flight

**Corrected for Flaperon Input

Figure 10 - Demonstrated Lift Performance of A-6/CCW Aircraft

of attack of only 16 degrees and an altitude of 5,000 feet, enabling the A-6 to fly at a speed of 67 knots. However, $C_{L_{max}}$ was never achieved in flight although an angle of attack of almost 30 degrees was flown at 15,000 feet. Therefore, all "maximum" values of C_L from the flight program are the maximum values of lift actually flown. These data are shown in Figures 10 and 11. Wind-tunnel results for the A-6/CCW are shown as solid lines in Figure 11. The maximum value of trimmed $C_{L_{max}}$ is shown as about 3.9 at a blowing coefficient (C_μ) of 0.30. Calculated values of trimmed C_L based on flight data are shown as the dashed lines and fall somewhat below the wind-tunnel data. However, during the flight program, the vehicle performance was such that a significant amount of spoiler (flaperon) action was required for maintaining a zero bank angle. An adjustment made to the data at 5,000 feet to correct for this lift loss yields a C_L of 3.60 generated by the CCW. This adjustment brings the wind-tunnel and flight data into agreement. This $C_L = 3.60$ is shown in Figure 10 and is also the value used in calculating the percent increase over the standard A-6 performance. On this basis, the value of $C_{L_{max}}$ at

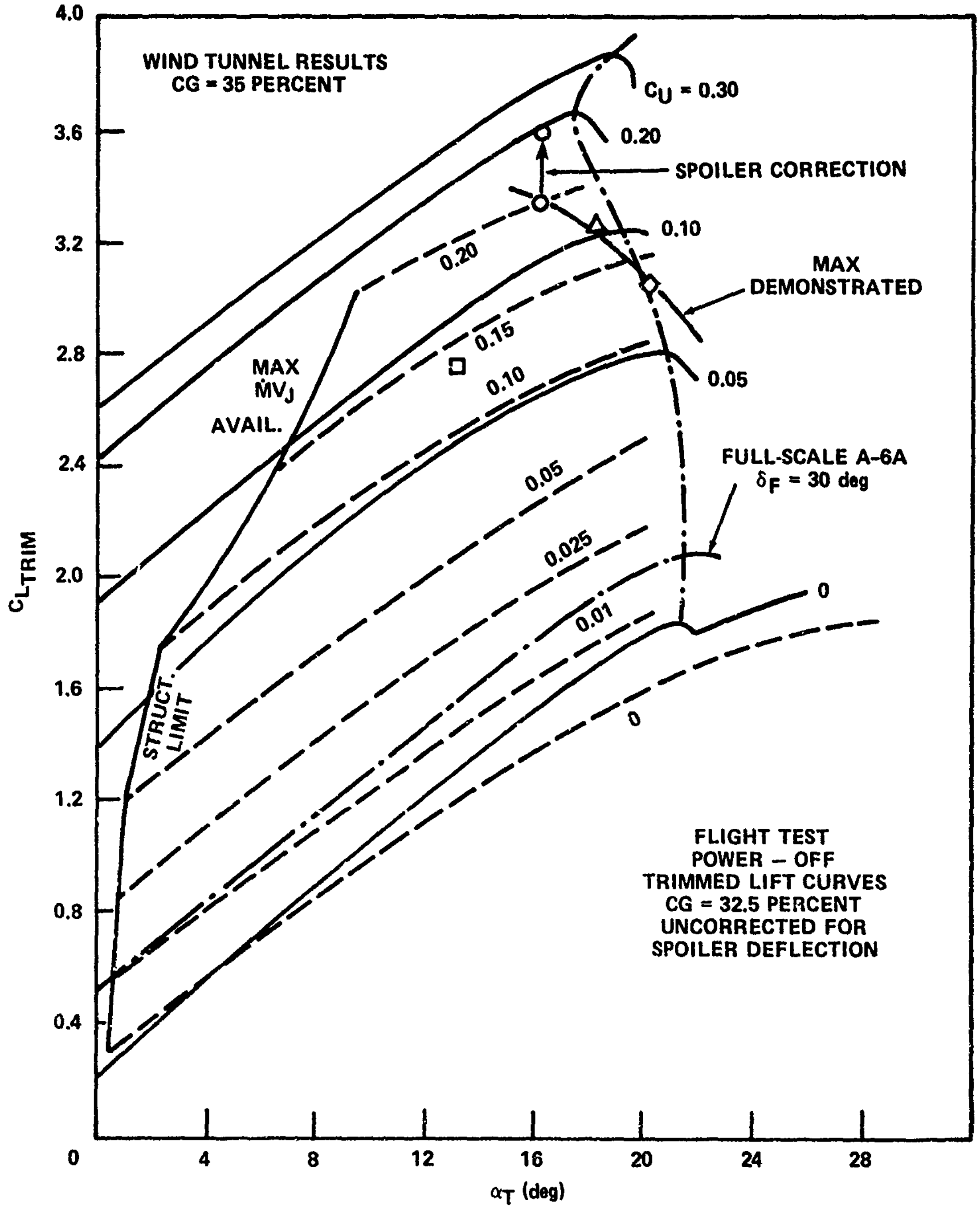


Figure 11 - Trimmed Lift Curves of A-6/CCW Aircraft

C_{μ} = 0.20 is likely to be about 3.7 which compares to a $C_{L_{max}}$ of about 2.1 for the standard A-6 with a 30 degree flap setting. Further, this $C_{L_{max}}$ is accomplished at an angle of attack of about 17 degrees, whereas the A-6/30 degree flap $C_{L_{max}}$ occurs at an angle of attack of about 22 degrees. As will be shown, the high lift capability of the CCW translates into significant takeoff and landing performance benefits.

For the flight demonstration, the CCW was powered by bleed air from the J52 engine. Engine tests, conducted by DTNSRDC at the Naval Air Propulsion Center, demonstrated the capability to bleed these engines as much as 16 percent of total airflow, however, the CCW system was designed to use a maximum of 11 percent (37 psig). When bleed air is diverted from the engine, there is a consequent loss in thrust. Also, as this bleed air is used to produce lift in the CCW, it also produces induced drag. Therefore, using 100 percent of the maximum pressure available does not provide the best takeoff performance. A careful examination of the use of bleed air showed that the best overall takeoff performance is achieved somewhere between 50 to 70 percent of the maximum bleed available for a takeoff procedure where the blowing is turned on at the point of rotation (see Figure 12). Furthermore, if blowing is employed from the beginning of the takeoff roll, the thrust loss and induced drag increase will penalize performance, and only about 20 percent of the maximum bleed available can be usefully employed for CCW. This was substantiated during the flight demonstration as both procedures were used. Calculations for an A-6 gross weight of 45,000 pounds are presented in Figure 12, however, the trends shown are quite representative for the range of gross weights for the A-6.

Takeoff and landing performance is summarized in Table 1. In evaluating these performance gains for the A-6/CCW, it is important to consider that neither the flight nor the flight operations were optimized to the extent of demonstrating the full potential of the CCW system. This is particularly true for maximum takeoff and landing performance. The detrimental effect of using spoilers has already been discussed.

A takeoff distance of 700 feet was measured for 60 percent maximum pressure takeoff. However, this distance was enhanced by a headwind and

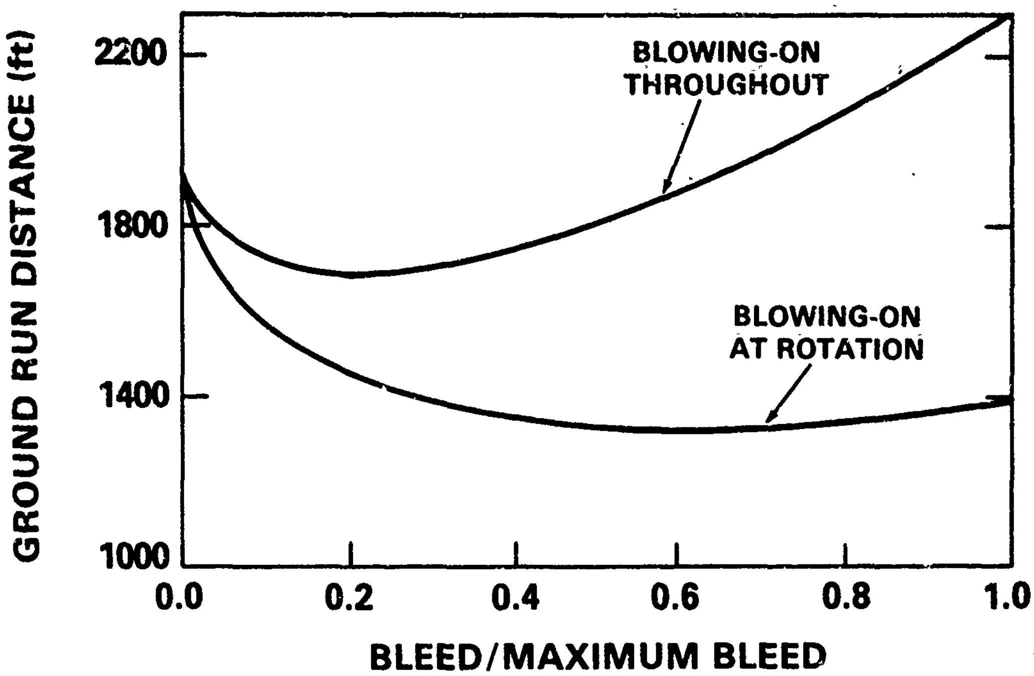


Figure 12 - Effect of Engine Bleed on Takeoff Performance

a nonstandard day. When adjusted to a standard day with no headwind for comparison purposes, this distance extends to 865 feet. Examining takeoff performance in further detail, a comparison of the A-6 and A-6/CCW is made in Figure 13. The solid curve shows the standard A-6 takeoff characteristics at a gross weight of 35,700 pounds and is extended below the minimum takeoff distance to indicate performance potential with higher $C_{L_{max}}$ than is now available. Only three measured takeoffs were accomplished in this flight program, therefore, the CCW demonstration points shown are not a good representation of CCW performance that could be achieved as standard procedure. That is, the best combination of angle of attack, point of rotation, etc. for a particular amount of blowing has not been established since more flight experience is necessary. These "unoptimized" takeoff procedures result in the CCW demonstration points falling above the 35,700 pound gross weight curve. Flight experience will result in further improvements in takeoff distances at any given takeoff speed. For example,

TABLE 1 - DEMONSTRATED LANDING AND TAKEOFF PERFORMANCE OF A-6/CCW AIRCRAFT

Approach, 3 deg Glide Slope, W = 33,000 lb

Standard A-6: V = 118 knots

CCW: V = 76 knots at 75 Percent Max. Pressure (C_L = 2.78)

Landings

Standard A-6: Min. Landing Dist. = 2250 ft, V_{APP} = 111 knots

CCW: 76 Percent Max. Pressure, Dist. = 1110 ft, V_{APP} = 85 knots (C_L = 2.58)

Takeoff, W = 35,700 lb

Standard A-6, δ_F = 30 deg: Normal Takeoff Dist. = 1500 ft, $V_{Liftoff}$ = 120 knots

Minimum Takeoff Dist. = 1160 ft, $V_{Liftoff}$ = 105 knots

CCW:

Percent Max. Pressure	Takeoff Distance (ft)	$V_{Liftoff}$ (knots)
20	1090	102
40	900	88
60	700 (865)	84

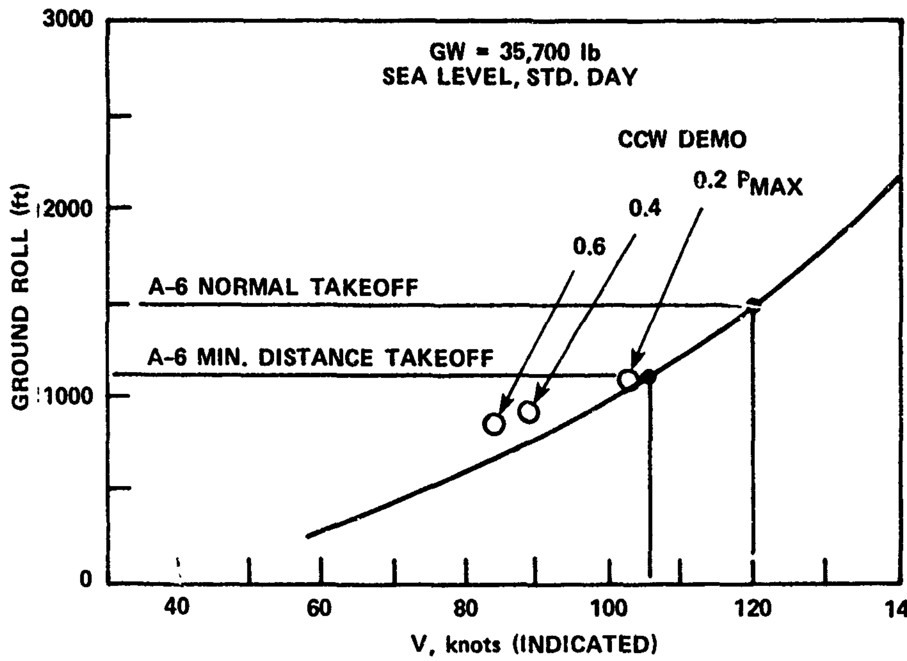


Figure 13 - Takeoff Distance and Speed of A-6/CCW Aircraft

taking off at 60 percent of maximum pressure for blowing can probably be accomplished in a ground roll distance of about 700 feet at 84 knots. This is less than half the distance required for the A-6 normal takeoff.

As anticipated, landing performance showed even greater improvements, due to the increase in drag at the high lift and high power settings experienced. Two landing distances are used in making a performance comparison: (1) a normal landing which is accomplished at a speed 30 percent higher than the aircraft stall speed, and (2) a minimum distance landing where the landing speed is only 20 percent higher than the stall speed. The solid curve in Figure 14 represents the A-6 landing characteristics. The gross weights shown along this curve are based on which landing method is used. The flight test data shown do not fall on the standard A-6 curve probably as a result of the higher power settings and different glide slopes possible for CCW. During the flight program, only one minimum distance

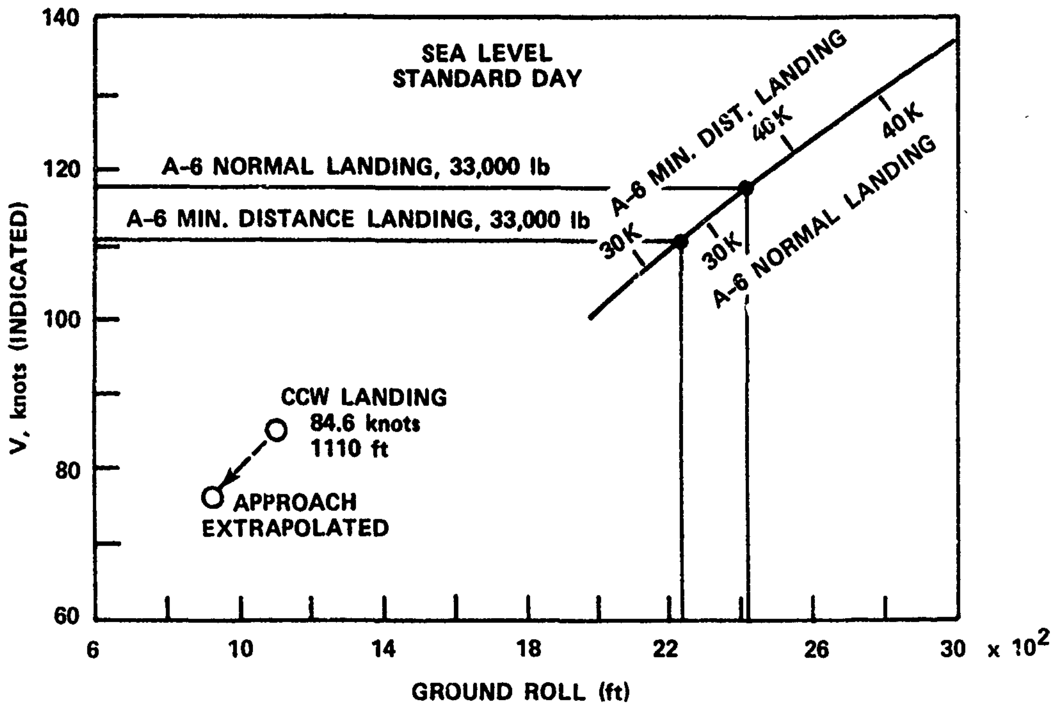


Figure 14 - Landing Distance and Speed of A-6/CCW Aircraft

landing was accomplished, this being flown at a relatively high approach speed of about 85 knots. Although an 1110 foot distance was achieved, the best approach speed flown was 76 knots (at 75 percent maximum pressure), but with no attempt to control groundroll. This approach speed would probably yield a minimum distance landing of about 900 feet.

A summary of actual STOL performance achieved by the A-6/CCW relative to the standard A-6 is shown in Table 2. A significant STOL performance has been demonstrated by the CCW system, even when considering the additional degree of attention required for improving the system hardware and increasing flight experience in order to achieve the best performance. In particular, the takeoff and landing performance can put the A-6 in a near-STOL category (if STOL still means 400 feet). And the potential for providing some degree of STOL performance to other conventional takeoff and

TABLE 2 - STOL PERFORMANCE SUMMARY OF A-6/CCW AIRCRAFT

	Goal (percent)	Demonstrated (percent)
Increase in Conventional A-6 $C_{L_{max}}$	81 (C_L = 3.8 at C_μ = 0.27)	71 (C_L = 3.6 at C_μ = 0.20)
Reduction in Power - on Approach Speed	30	32/36*
Reduction in Liftoff Speed	14	20/30
Reduction in Landing Ground Roll	50	51/54
Reduction in Takeoff Ground Roll	22	25/42

*Minimum distance effort/normal effort.

landing (CTOL) aircraft is clearly indicated. The full benefits of CCW will, of course, be achievable through any new aircraft specifically designed at the outset to incorporate the CCW system.

Experimental values of $C_{L_{max}}$ for the A-6/CCW with an aspect ratio of 5.3 are shown in Figure 15. Extrapolating these values to the 3.5 to 5.0 aspect ratio range and applying them to the conceptualized STOL aircraft yields conclusions similar to those obtained in the USB assessment. Operationally feasible CCW designs were generated for DTNSRDC by the Lockheed California Company, thereby providing credible weights and other useful design information. The mission performance analysis (Figure 16a) shows that the aspect ratio 5 STOL CCW aircraft can barely achieve the 300 nautical mile mission radius within the specified gross weight range, and then only with a wing span greater than about 53 feet. If the aspect ratio is lower (Figure 16b), the 300 nautical mile radius cannot be achieved within the desired specified parameters. A better engine airframe match can be achieved by duct burning and better T/W performance of CCW can be shown (Figures 16c and 16d) for a lower range of aspect ratios. However, the wing span requirements are still too large for compatibility with an LPH size ship which imposes a limit of 45 feet, although spans on the order of 52 feet are indicated for an aspect ratio 4.25 STOL CCW aircraft.

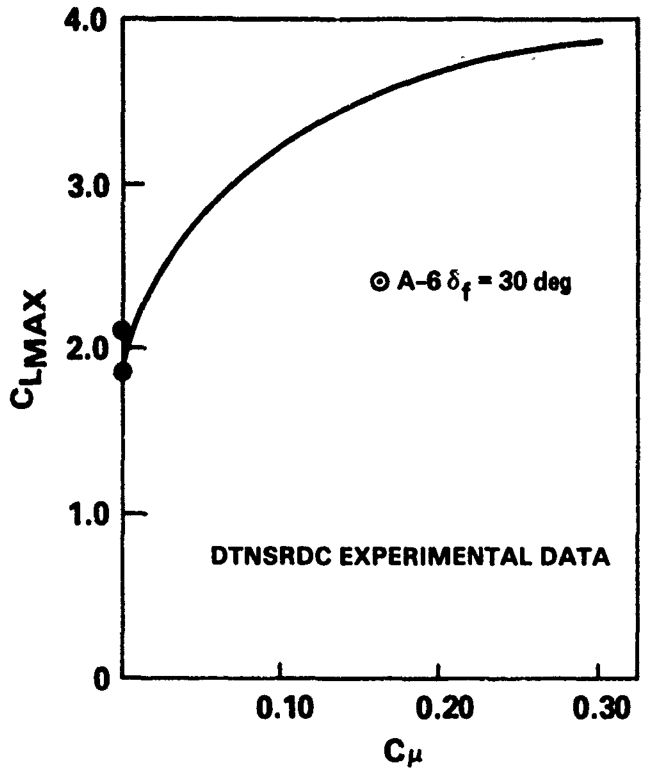


Figure 15 - Maximum Lift of Circulation Control Wing on A-6 Aircraft

OVERALL ASSESSMENT FINDINGS

A comparison of circulation lift produced by both CCW and USB is shown in Figure 17. The USB system operates best in a range of C_μ of around 3 and can achieve a circulation lift of about 6, whereas the CCW system operates best in a range of C_μ around 0.3 and can achieve a circulation lift of about 4 1/2.

Either of these high lift devices, as well as CSB and AJF systems, could provide the lift required for a 400 foot takeoff within a desirable range of wing loadings and achieve a 300 nautical mile mission. However, the resulting aircraft wingspans required consistently exceed a 45 foot LPH ship requirement. Therefore, if aircraft are indeed going to be operated from small ships, a better propulsion match and an aerodynamic breakthrough in high lift and cruise enhancement will be in order.

An experimental program has been designed to push for such a breakthrough by evaluating the various combinations of powered lift systems with

Figure 16 - Mission Performance of STOL CCW Aircraft

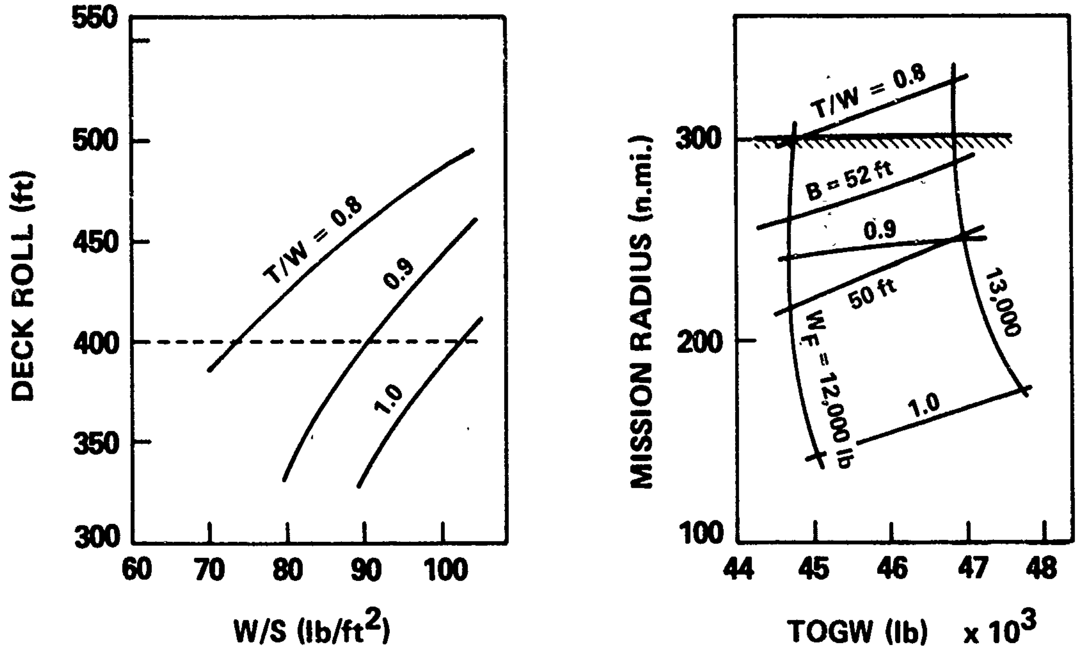


Figure 16a - W/S, T/W, and Wing Span Requirements for Æ = 5.0 STOL CCW

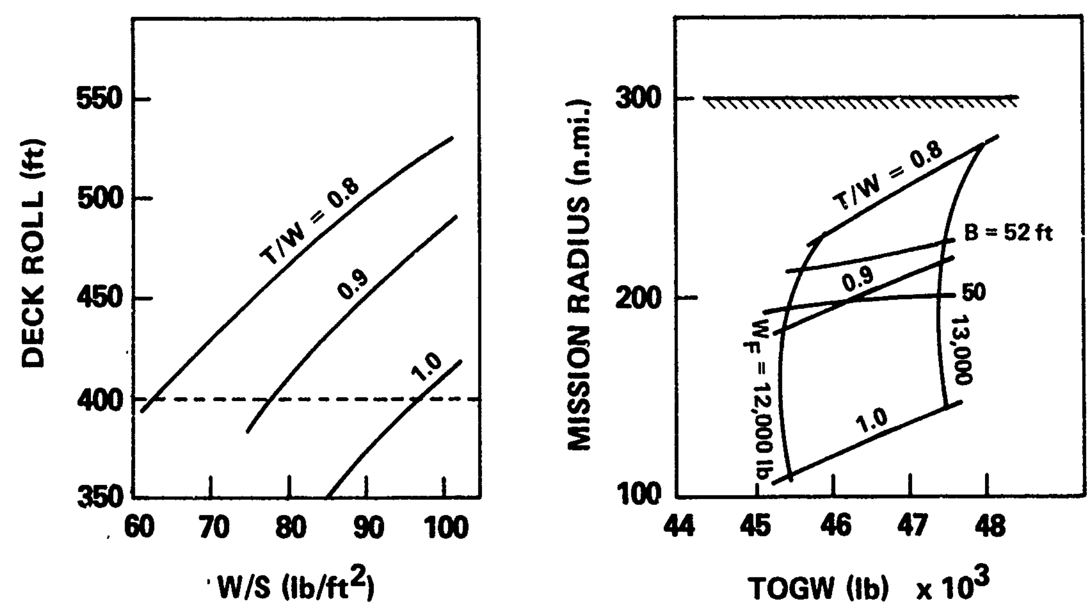


Figure 16b - W/S, T/W, and Wing Span Requirements for Æ = 4.25 STOL CCW

Figure 16 (Continued)

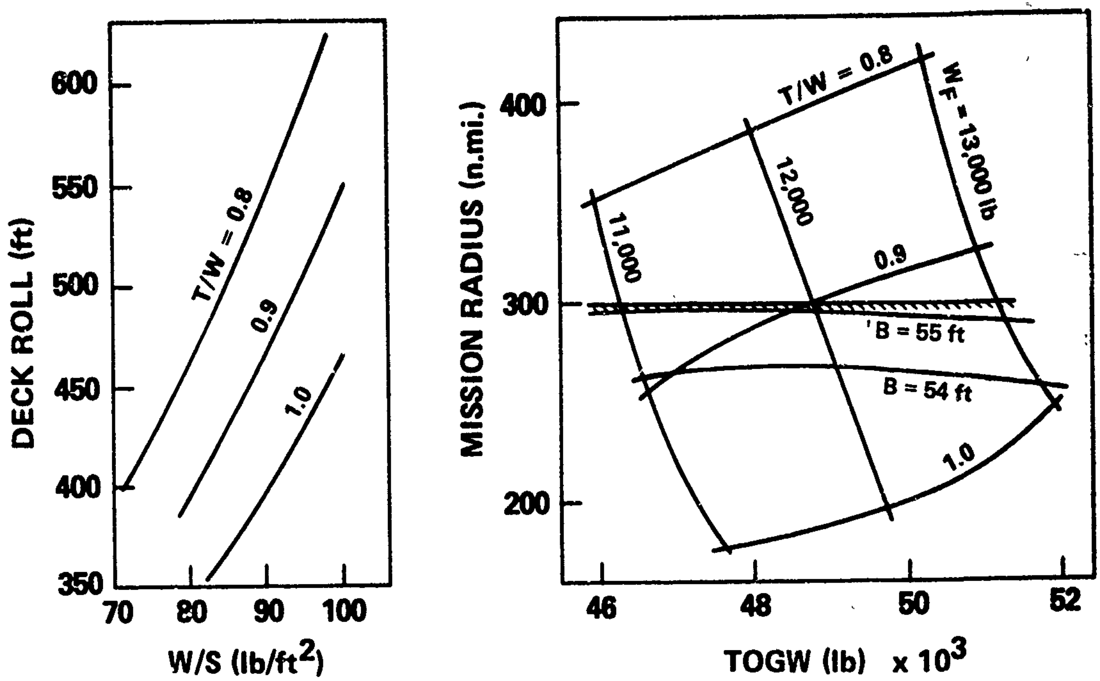


Figure 16c - W/S, T/W, and Wing Span Requirements for Æ = 5.0 STOL CCW 50 Percent Duct Burning

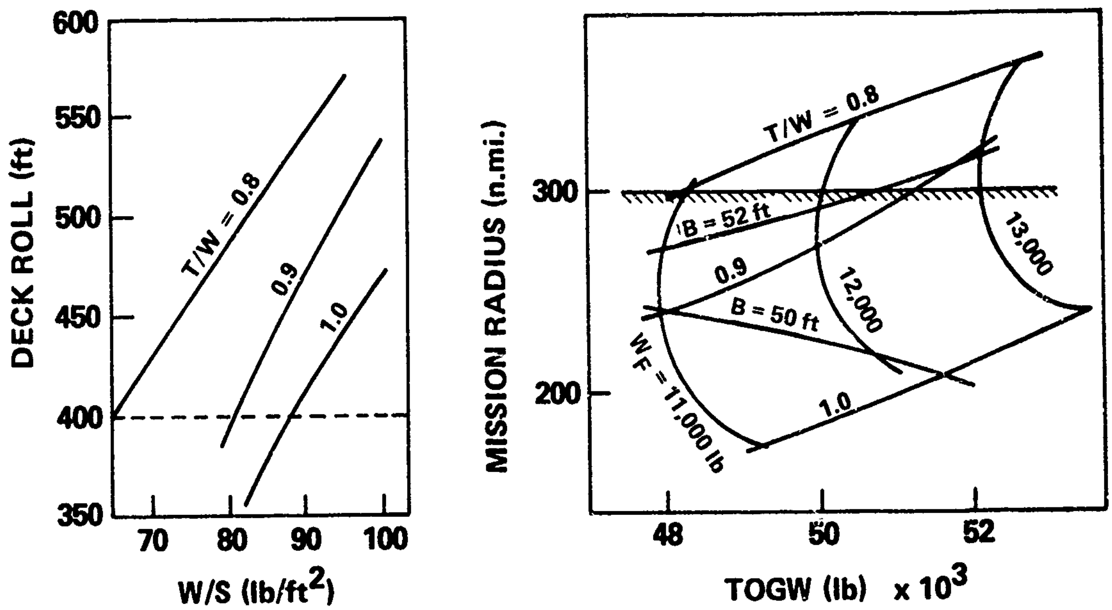


Figure 16d - W/S, T/W, and Wing Span Requirements for Æ = 4.25 STOL CCW 50 Percent Duct Burning

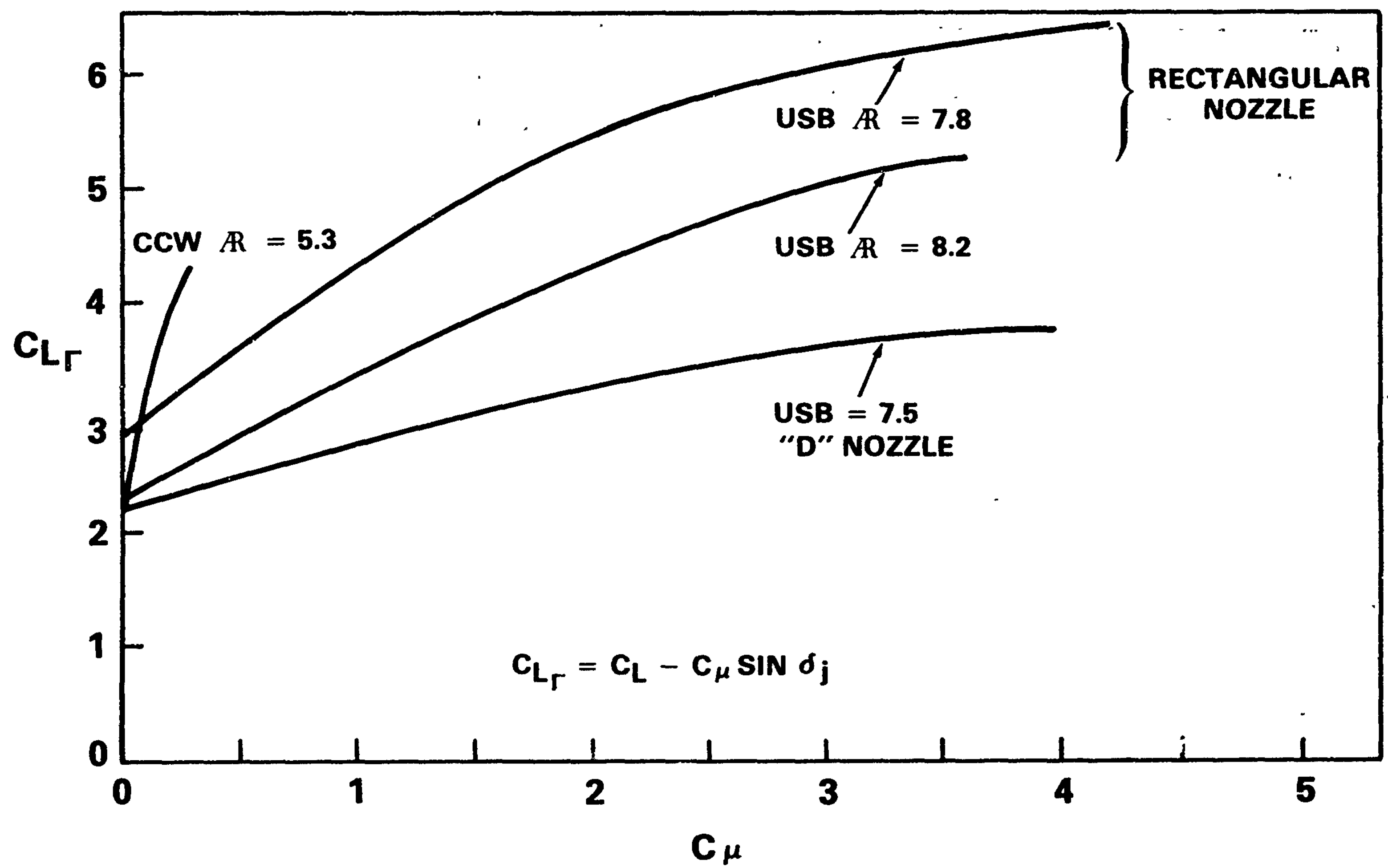


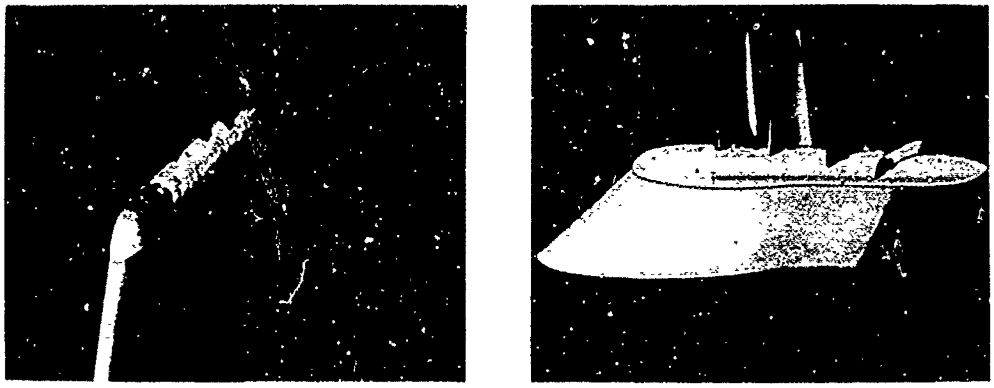
Figure 17 - Circulation Lift Comparison, Upper Surface Blowing, and Circulation Control Wing

cruise enhancement devices. The potential result could be the development of a synergistic combination that provides the maximum efficiency needed for the high lift system as well as provides the means for increasing the effective aspect ratio for improved cruise thereby further reducing the weight and wingspan.

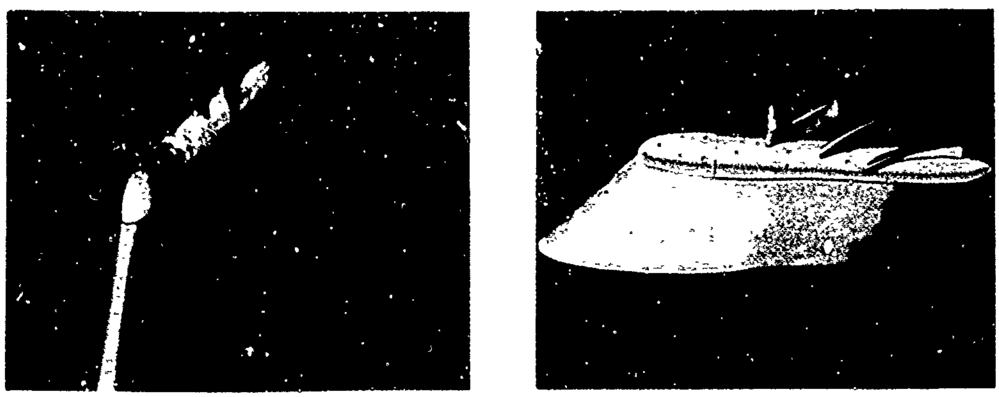
POTENTIAL HIGH LIFT AND CRUISE ENHANCEMENT DEVICES

The technology for improving cruise performance by devices to increase effective aspect ratio has had considerable attention over the years. The recent development of winglets and wing tip sails by NASA and the Cranfield Institute in England, respectively, have successfully shown attractive benefits in reducing induced drag, and both devices will offer significant cruise performance benefits when fully perfected and applied. The winglets go a step beyond what an end plate can do by providing a force component in the forward direction. The tip sails have an effect of unwinding the tip vortex, increasing the lift contributed by the outer portion of the wing, thereby making the wing more two-dimensional. An extension of the tip sail technology has been hypothesized by DTNSRDC by applying the knowledge gained during the considerable effort put into close-coupled canard technology development. The favorable interference generated between the canard and wing can possibly be duplicated in a close-coupled-cascade arrangement. The tip sail and close-coupled-cascade devices are shown in Figure 18 as they have been arranged for wind-tunnel experiments.

Preliminary work using tip blowing was done at DTNSRDC in conjunction with the X-Wing program. Blowing from the rounded tip shifted the tip vortex core outward and upward which showed the potential for improving cruise performance (Figure 19). This approach has shown enough promise to warrant further pursuit. In addition, the use of blowing on the winglet is of interest. For example, a winglet design that will enhance the high lift performance may very well be different from the winglet designed to enhance cruise performance. The use of blowing potentially offers to bridge the resulting tradeoff gap.



TIP SAILS



CLOSE-COUPLED CASCADE

Figure 18 - Wing Tip High Lift and Cruise Enhancement Devices

Although the potential improvements in cruise performance have been amply demonstrated, the hypothetical improvements in high lift enhancement have yet to be arranged. The most important challenge will then be to orchestrate the designs resulting from cruise and high lift enhancement into a single device or system that will aerodynamically accomplish both objectives.

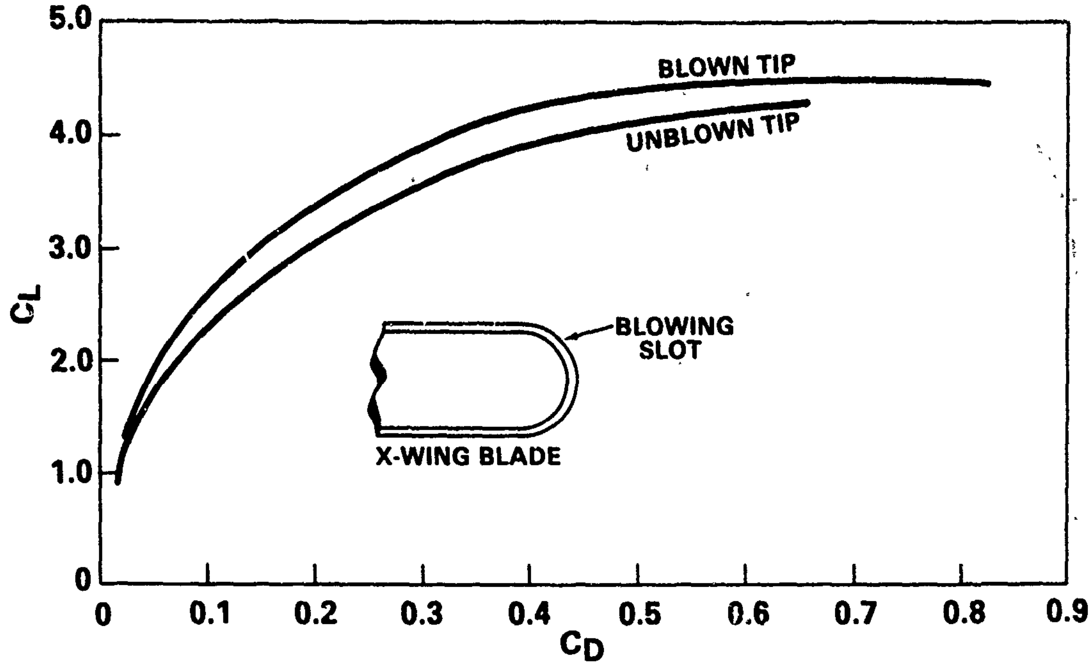


Figure 19 - Cruise Performance Improvement Potential from Tip Blowing

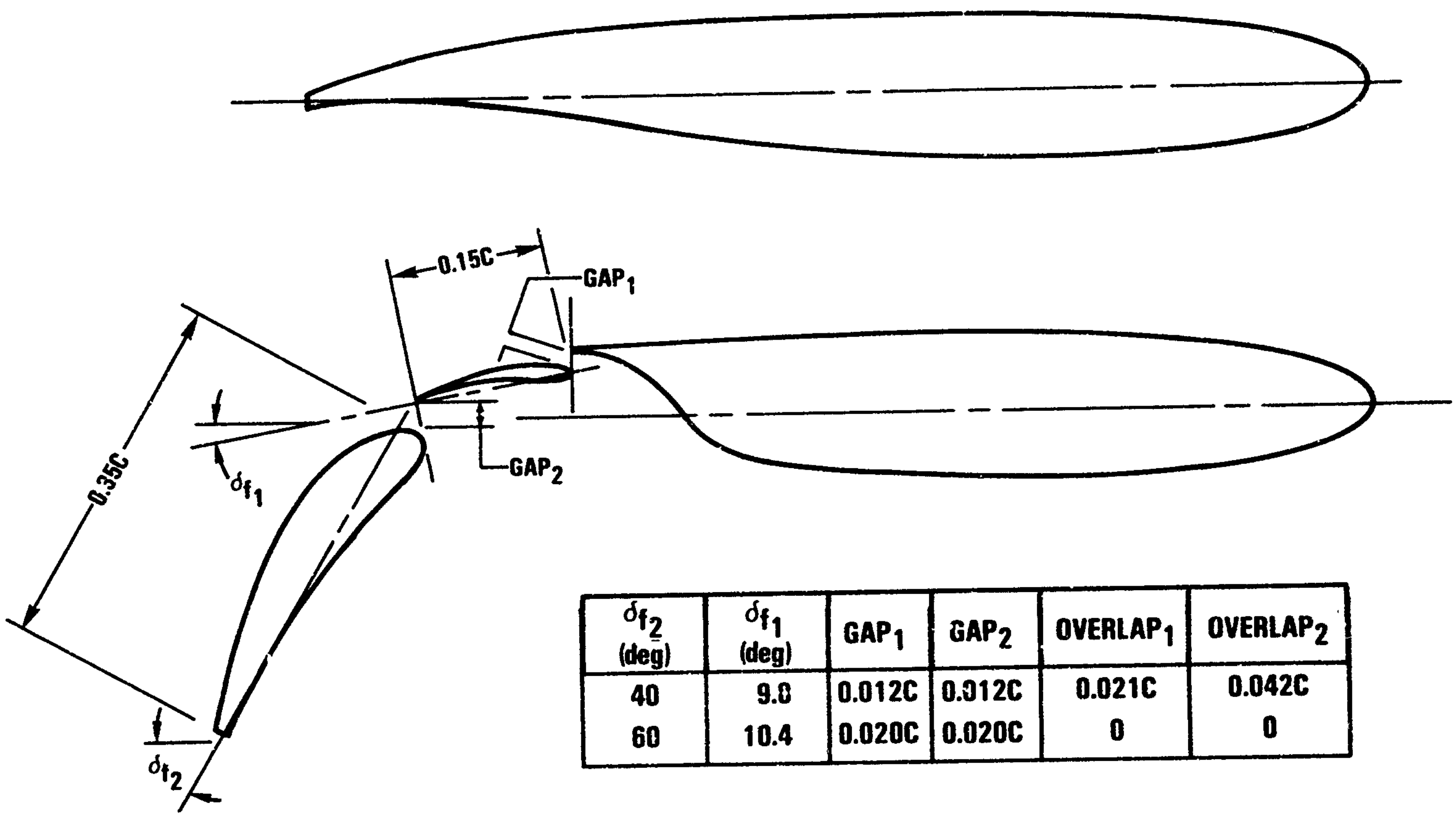
EXPERIMENTAL PROGRAM

The experimental program is built around a NASA supercritical wing design which incorporates a double-slotted flap (Figure 20), thereby representing a reasonable baseline of the state-of-the-art in unpowered high lift technology. The wind-tunnel model is presently designed for three aspect ratios (3.1, 4.0, and 5.2) in order to make a unique evaluation of aspect ratio effects. The model presently accommodates both USB (Figure 21) and CCW systems as well as various tip devices (for example, those shown in Figure 18).

Experimental results have thus far focused on the basic high lift performance of the DSF, USB, and CCW systems. Initial wing tip work has been done with an end plate which is shown in Figure 21.

DOUBLE-SLOTTED FLAP

Typical DSF performance on aspect ratio 3 and 4 wings is shown in Figure 22. A $C_{L_{max}}$ of nearly 2.4 at a flap setting of 60 degrees is achieved



δ_{f_2} (deg)	δ_{f_1} (deg)	GAP$_1$	GAP$_2$	OVERLAP$_1$	OVERLAP$_2$
40	9.8	0.012C	0.012C	0.021C	0.042C
60	10.4	0.020C	0.020C	0	0

Figure 20 - Double Slotted Flap Assembly

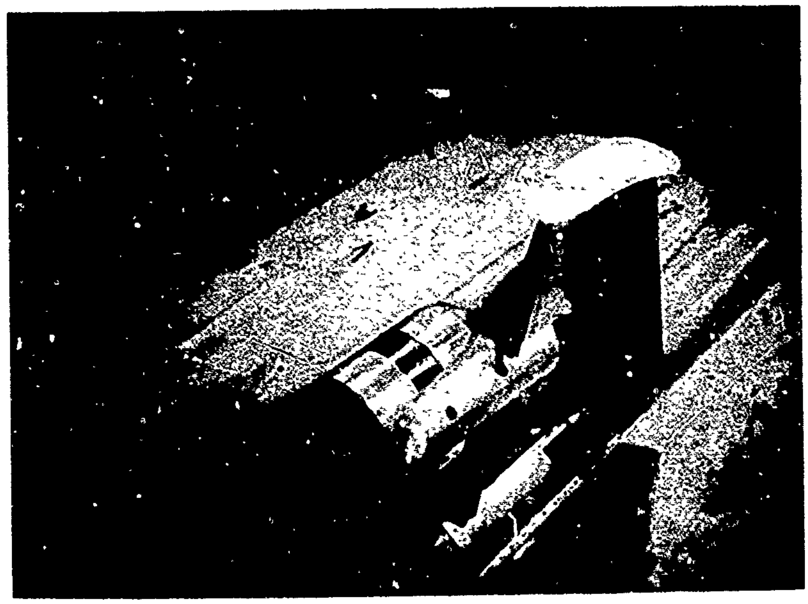


Figure 21 - Tip Fence Installation

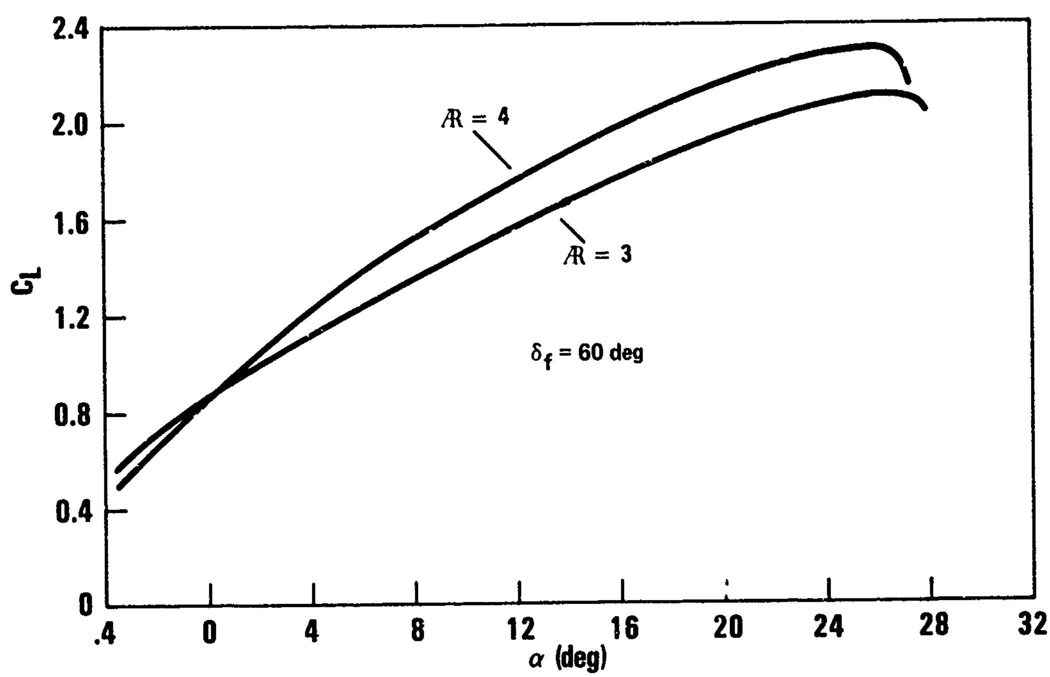


Figure 22 - Double Slotted Flaps

at about 26 degrees angle of attack on the aspect ratio 4 wing. Reducing the wing aspect ratio to 3 reduces the achievable $C_{L_{max}}$ to about 2.2. A 40 degree flap setting could only produce a $C_{L_{max}}$ of 2.1 and 1.9 for aspect ratio 4 and 3 wings, respectively (not shown).

UPPER SURFACE BLOWING

The USB model accommodates nozzle aspect ratios of 2, 4, and 6. Not surprisingly, the aspect ratio 6 nozzle has given the best lift performance since the exhaust jet encompasses most of the flap system. However, the practicality of such an arrangement for a low aspect ratio wing is questionable. At this time, our limited air supply has precluded the USB model from being operated beyond a C_μ of about 1.5. The Tech Development fan being used will operate at a much higher capacity and arrangements are being made to increase C_μ to at least 3.0, which will be adequate for this evaluation. At this moderate value of C_μ, USB produced a C_L of 2.8 for the aspect ratio 3 wing and aspect ratio 6 nozzle and did somewhat better with a C_L of 3.3 for the aspect ratio 4 wing and aspect ratio 6 nozzle (Figure 23). The data shown in this figure are for the USB model with a tip fence

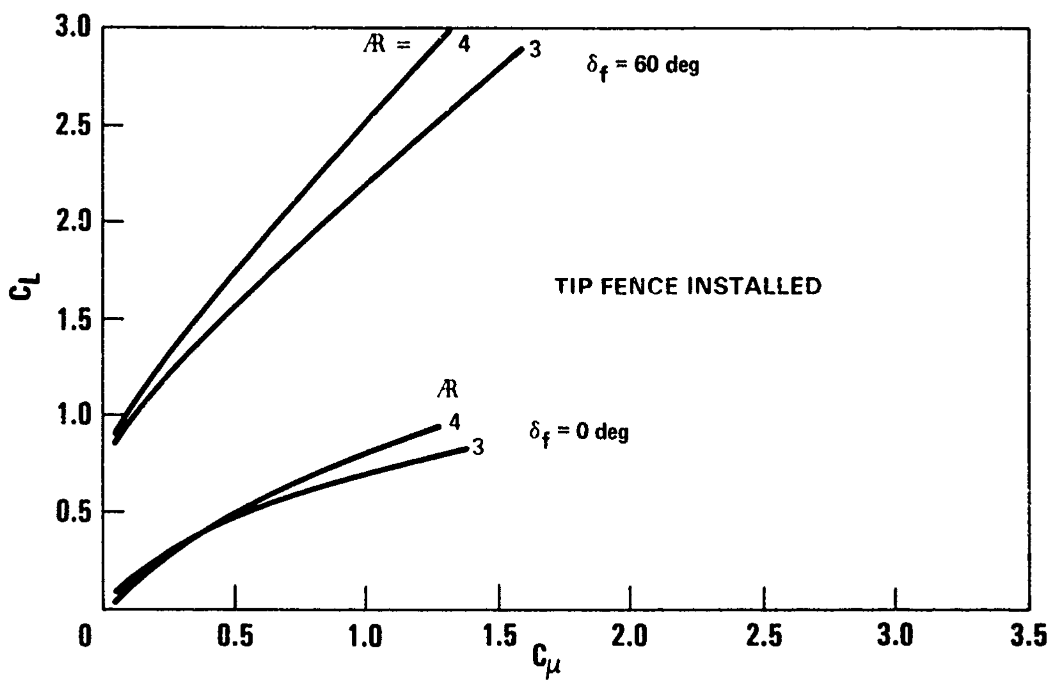


Figure 23 - Lift Curve for Upper Surface Blowing Model

GPO 887-382

installed (Figure 21) since it appeared that considerable flow separation was occurring over the outboard portion of the wing. There was some indication that this tip fence arrangement may offer improved high lift capability at higher values of C_μ than were used, however, the lift gains were insignificant at C_μ up to 1.5. Furthermore, there will be some exhaust jet impingement on the tip fence at the high nozzle aspect ratio and low wing aspect ratio combination which may counteract any gains achieved. It is certain that flow improvements are necessary, however, it is anticipated that these flow improvements will be better accomplished with some of the other tip devices. The experiments conducted so far have not simulated a double-slotted flap outboard of the exhaust jet (the configuration employed by the YC-14). This is easily accomplished and will be done in the near future. This arrangement promises to show some lift gains, particularly for the lower aspect ratio nozzles.

CIRCULATION CONTROL WING

The CCW configuration represents a first attempt at a low aspect ratio (below 5) application in an otherwise extensive technology development program involving both rotary and fixed wing aircraft. Where a $C_{L_{max}}$ of 3.9 at a C_μ of 0.3 was achieved experimentally with an installation on the aspect ratio 5.3 A-6 wing, the effect of reducing aspect ratio is significant (see Figure 24). A $C_{L_{max}}$ of only 3.0 was initially reached on the aspect ratio 4 wing which is only a moderate increase over the $C_{L_{max}}$ of 2.4 of the 60 degree DSF. A further reduction in aspect ratio to 3 resulted in a further reduction in $C_{L_{max}}$ to barely over 2.6 which approaches the 60 degree DSF value of 2.2. Furthermore, where increased C_μ tended to increase $C_{L_{max}}$ at least up to $C_\mu = 0.3$ for the aspect ratio 5.3 wing, the best $C_{L_{max}}$ was reached at a C_μ near 0.18 for the lower aspect ratio wings.

In examining the flow around the wing, it was found that considerable flow separation was being induced over the outboard portion of the wing caused by the effective flow discontinuity occurring between the region of

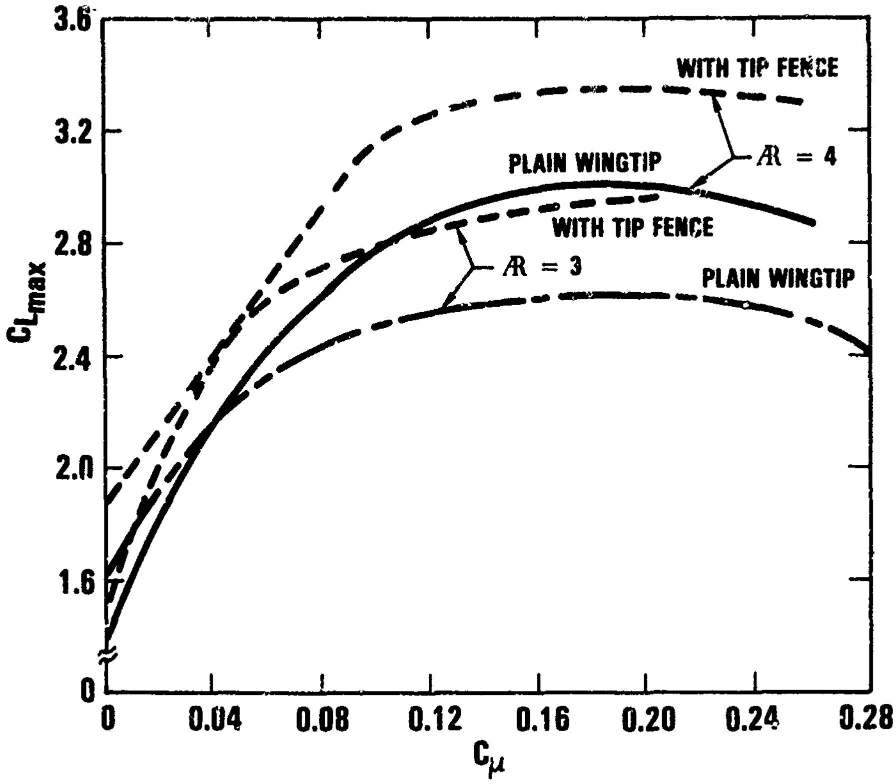


Figure 24 - Tip Fence Effect on Circulation Control Wings

strong circulation over the wing and the flow at the tip. The installation of an end plate ("tip fence") offered to resolve most of this problem and an increment of 0.4 was restored to $C_{L_{max}}$ generating more competitive values of 3.4 and 3.0 for respective aspect ratios of 4 and 3. It is evident that further work is still required to fully restore the flow and, as in the case of USB, various tip devices will be used to accomplish this purpose.

CONCLUDING REMARKS

The desire to operate fixed wing aircraft from small ships poses many dilemmas. A real challenge lies in trying to create an aircraft for such shipboard operations and yet still perform meaningful missions. The requirements for a small wing span for physical fit and for high speed flight conflicts directly with the requirements for adequate (if not excellent) short takeoff and landing ability and for efficient cruise flight--whether the aircraft is VSTOL, STOVAL (short takeoff and vertical attitude landing), or STOL (or even CTOL).

This effort addresses a critical need to fully exploit both high lift and improved cruise technology for use on low aspect ratio wing aircraft that can fulfill the above requirements. Although the new technology powered high lift systems offer excellent short takeoff and landing capability, they all are seen to lose their effectiveness when applied to a short wing span. However, the employment of appropriately designed tip devices offers the potential of not only improving cruise performance but also restoring much of the high lift capability. The experimental program is being enthusiastically pursued to this end.

In the mean time, a new technology has been developed that offers another option in producing high lift. The CCW concept is now a reality. An extensive technology program has been pursued by DTNSRDC and proven in flight by Grumman on their A-6 aircraft. The CCW offers a finesse approach rather than a brute force approach and can be accomplished with the same level of complexity (or simplicity) as state-of-the-art systems in use, as evaluations by Grumman and Lockheed have shown. The CCW is certainly not a panacea, but it has earned an important and permanent place on the high lift aerodynamics shelf for serious consideration in achieving a short takeoff and landing performance capability. The potential for CCW as a maneuvering device has yet to be developed but the potential as such is becoming recognized.

The high lift business can best be put in perspective by viewing Figure 25. At the aspect ratios under consideration, some current aircraft can operate in the $C_{L_{max}}$ range of 1.0 to 1.5. Some advanced aircraft concepts show the potential for operating in a much higher range around 2.0, although this is still far short of what is theoretically attainable. However, based on the experimental data generated so far, powered lift systems seem to overcome that which the conventional systems cannot. And they can be encouraged to exceed even the limits imposed for theory for conventional systems as long as they get a little help.

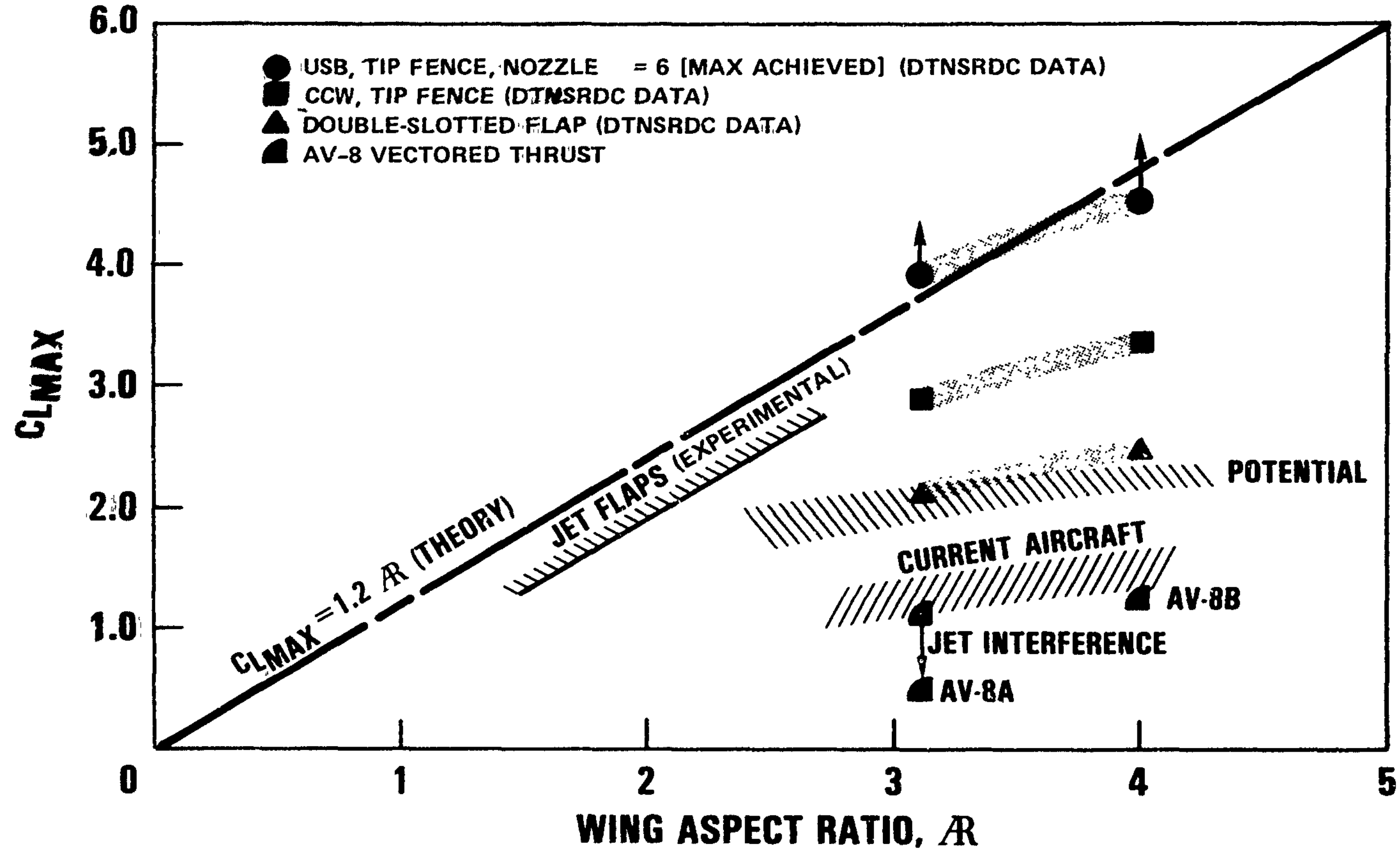


Figure 25 - Maximum Lift Achievable for Low Aspect Ratio Wings for Conventional and Powered Lift Systems

ACKNOWLEDGMENT

Significant technical contributions to this report were made by Mr. Lynn A. Trobaugh now at NAVAIR and Mr. Robert J. Englar, Mr. Michael J. Harris, and Dr. Roger J. Furey of DTNSRDC.

REFERENCE

1. Englar, R.J., "STOL - The Potential of the Circulation Control Wing Concept," Naval Engineer's Journal, Vol. 91, No. 2 (Apr 1979).

INITIAL DISTRIBUTION

Copies	
4	CNO
	1 RADM D.F. Mow (NOP 05V)
	1 R.H. Thompson (NOP 50W1)
	1 CAPT M.D. Beach (NOP 506C)
	1 CAPT F. Gallo (NOP 5060)
1	CMC, HQ
	1 COL N.F. Schnippel, Jr. (MC-RD-2)
1	DDR&E
	1 R. Siewert (OSD)
2	CNR
	1 D.C. Lauver (ONR 210)
	1 D.S. Siegel (ONR 211)
3	CHNAVMAT
	1 LTCOL R.W. Bowles (MAT 08TM)
	1 O.J. Remson (MAT 08T22)
	1 H. Moore (MAT 08D4)
1	ASN
	1 Dr. R.E. Reichenbach (RE&S)
1	NRL/Library
1	NAVAIRDEVCEN/ADT Library
1	NAVPGSCOL/Library
1	USNA/Library
10	NAVAIRSYSCOM
	1 CAPT Short (AIR APC-8)
	1 H. Andrews (AIR 03PA)
	1 S.J. Flickinger (AIR 03PA2)
	1 W.T. Sparrow (AIR 03PA3)

Copies	
	NAVAIRSYSCOM (Continued)
	1 T.S. Momiyama (AIR 03PA4)
	1 D.G. Kirkpatrick (AIR 320D)
	1 F.J. Paglienete (AIR 528)
	1 F. O'Brimski (AIR 5284B)
	1 L.A. Trobaugh (AIR 5284C1)
	1 Library (AIR 950D)
12	DTIC
2	NASA, Hugh L. Dryden Flight Research Center
	1 R. Klein
	1 Tech Library
4	NASA, Ames Research Center
	1 A. Faye
	1 D. Hickey
	1 J. Cochrane
	1 Tech Lib
2	NASA, Langley Research Center
	1 J.F. Campbell
	1 Tech Library
1	NASA, HQ
	1 A. Gessow
1	USAF (AFRDT-EX) Research & Technology
1	AFFDL/Tech Library
1	FAA V/STOL Prog. (DS-22)
2	Rockwell International Columbus Division
	1 William E. Palmer
	1 Tech Library

PRECEDING PAGE BLANK-NOT FI

Copies

1 Fairchild-Hiller/Germantown
  1 Tech Library

2 Northrop Corp/Hawthorne
  1 Aircraft Division
  1 Tech Library

2 Lockheed Aircraft Corp/
  Lockheed, Georgia
  1 C. Dixon
  1 Tech Library

4 Lockheed Aircraft Corp/
  Lockheed, California
  1 J. Hippler
  1 A. Burns
  1 T. Priestly
  1 Tech Library

2 McDonnel-Douglas Aircraft
  Corp./Douglas Aircraft
  Co./Long Beach
  1 F. Posch
  1 Tech Library

3 Grumman Aerospace Corp.
  1 M. Ciminera
  1 M. Siegal
  1 Tech Library

1 General Dynamics
  Convair Division
  1 Tech Library

1 General Dynamics
  Ft. Worth
  1 Tech Library

1 LTV/Dallas
  1 Tech Library

1 McDonnell-Douglas Aircraft
  Corp./St. Louis
  1 Tech Library

2 Boeing Co./Seattle
  1 E. Omar
  1 Tech Library

CENTER DISTRIBUTION

Copies	Code	Name
10	166N	J. Nichols
10	5211.1	Reports Distribution
1	522.1	Lib (C)
1	522.2	Lib (A)
2	522.3	Aerodynamic Lib